

BLIND GUIDANCE BY ULTRASONICS

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Experimental model of a 32-kc pulsed frequency modulation blind guidance system. Headphones can be replaced with bone conduction unit, and use of 65 kc allows smaller double-transducer assembly (see Fig. 1).

BLIND GUIDANCE

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To investigate the possibilities of developing artificial devices to aid the military blind, the Committee on Sensory Devices was organized in 1944 under the jurisdiction of the Office of Scientific Research and Development. The Haskins Laboratories of New York City was selected by the Committee on Sensory Devices to serve as a central laboratory for the Committee in guiding the efforts of various groups doing the research and development and also to carry on tests with blind subjects. The Stromberg-Carlson Company was one of three industrial organizations chosen to develop blind guidance devices using ultrasonic echo-ranging techniques. In September 1945, the

Committee on Sensory Devices was transferred to the National Research Council and the financial support of the research program was taken on jointly by the Surgeon General of the War Department and by the Veterans Administration.

While the idea of a person's carrying around a portable radar-like device originally seemed rather fantastic, there was the precedent of the bat's use of an acoustic form of echo ranging^{1,2} and of a blind person's use of audible sounds to locate walls and other fairly large obstacles.³

System Limitations

Although at first the form of the guidance device was only loosely defined, it was natural to assume that

it would be something like a flashlight which the user could point in various directions. The signal would probably be some audible indication of the distance to the obstructing object. The maximum distance range that seemed desirable changed with experience.

At first, the tentative specifications called for a maximum range of at least twenty-five feet, and fifty feet if possible. Later experience with systems which did have a range of fifty feet or more showed that there was a large amount of information about distant objects that was of no immediate use and actually caused confusion. A blind subject, for example, walked with much more confidence if the guidance device gave no indication of objects beyond eight feet than he

From a paper presented at the 1947 National Electronics Conference in Chicago.

Wheeler addressed themselves to an old problem: Can radio waves be transmitted deep in the earth? Calculations had indicated subsurface exploration as deep as 5,000 feet might be possible by reflection of radio waves from strata, assuming a system amplification of 150 db. The Bureau of Mines had received radio waves at broadcast frequencies several hundred feet below the surface under circumstances which indicated direct passage through the earth. A joint investigation by Seaboard Oil Company and Hazeltine was set up to determine what might be done, using wave frequencies from 0.5 mc to 1,000 mc. Initial successful transmission through 600 feet of earth proved impossible to repeat. Later it was noted that the first observation had been made following a prolonged dry spell, whereas later attempts had followed heavy rain fall. A final determination was made by lowering a transmitter and receiver through separate drill holes, with the holes capped so that any energy detected would have to pass through the ground. Variations in loss as high as 1 db per foot were observed between layers of shale and sand, and the variations were closely correlated with changes in structure. Ground moisture introduces such losses that it was concluded that this method of geophysical prospecting was impractical. The method has some chance of success when used to locate water in very dry regions, however.

New Microwave Oscillator

E. D. McArthur of General Electric described a new type of triode, now in the development stage, which may prove useful as a generator of microwaves for such purposes as local oscillation and signal generation. The tube, called a dyotron, is a conventional triode containing a bypass capacitor of about 70 μ f within the envelope connected directly between grid and cathode, thus effectively removing any r-f potential between grid and cathode. The tube then becomes a two-terminal device, so far as r-f is concerned. Oscillation occurs as a result of the penetration of the grid-anode field through the grid.

A new branch of communications technology, christened cybernetics, was discussed by Norbert Wiener of M. I. T. This system brings the nervous system and its psychological attributes explicitly into the communications system as a functional element and studies the capacity of the individual to assimilate and use the information offered by the system.—D.G.F.

The growing importance of electronics in nuclear studies was reviewed in two sessions, and announcements were made of the cooperative effort of several technical societies to set up a uniform glossary of nuclear terms.

Theory is better understood.

Found for it, now that the basic

opined that new uses would be

cent history of this circuit and

Harold Wheeler reviewed the re-

by B. D. Loughlin of Hazeltine.

circuit for f-m reception, was given

nique, the design of the Fremodyne

function. An example of this tech-

the time function to the frequency

form is employed to convert from

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circuit drawing a causal connection

presented a unified theory of this

subject. W. E. Bradley of Philco

by a session of five papers on this

generative receivers was evidenced

A rebirth of interest in superre-

Superregeneration

The frequency range depends on of oscillation. cathode to regulate the frequency

may be applied between grid and

back circuit is required. D-c bias

cathode current. No external feed-

structure so that it affects the

an old problem: Can radio waves be

transmitted deep in the earth?

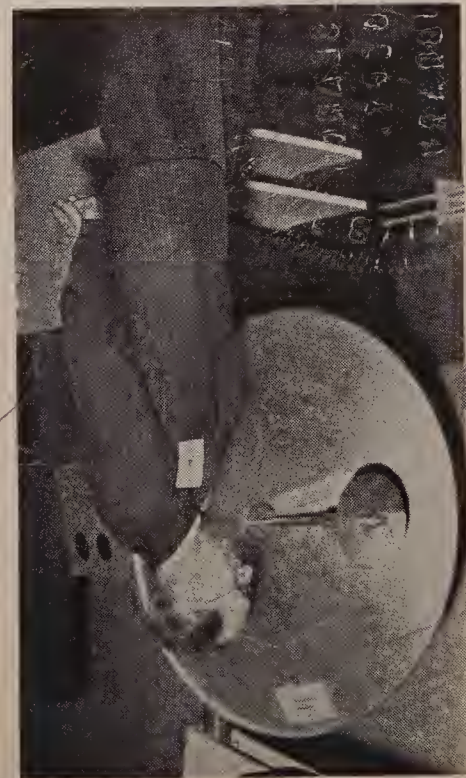
Calculations had indicated subsur-

Diode Rectifier Motor Control

Thyratron motor controls to secure a high value of torque at low speeds in motors, now commonly used in machine tool drives and other industrial applications, can be improved to the extent of a 50 per cent increase in torque, by the circuit described by W. N. Tuttle of General Radio. In this circuit a variable transformer (Variac), a choke and a full-wave vacuum diode rectifier are used to feed the arma-

ture of a d-c shunt motor. The low cost of vacuum full-wave rectifier tubes makes it possible to provide current capacity sufficient for instant starting, and the space requirements for the control are considerably less than that of the equivalent thyatron control. A one-third h-p motor can be controlled by such a circuit in a case 9 by 5 by 12 inches. By reversal of the armature current it is possible to provide dynamic braking in addition to speed control. A constant increment in speed from no load to full load is obtained over the full range of speed control, which may cover a range as wide as 20 to 1.

Two well known figures in radio, Knox McIlwain and Harold A.



The radiator for a big-dish antenna displayed at the IRE meeting is examined by George McIntire of WJEL, Winchester, Virginia

using a cascade amplifier of this type at 30 mc.



FIG. 1—Magnetostriction transducers used in the 32-kc (left) and 65-kc devices

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Portable radar-like device employing pulsed frequency modulation gives a single audio frequency tone corresponding to any given obstacle distance. Simultaneous echoes from different distances are identified by combinations of individual tones. Complete experimental equipment weighing $5\frac{1}{2}$ pounds operates at 65 kc to detect obstacles up to 30 feet

by ULTRASONICS

did if he had to sort out and interpret information indicating many distant objects. Whether a prolonged training period would make it possible for the subject to ignore the distant signals, except when they were of real interest, is open to question.

A fundamental limitation of any echo-ranging system is the fact that the type of information which a blind person expects from a guidance device can not always be obtained by echo-ranging. An open door, for example, is difficult to find from the opposite side of a room. Unless the beam of ultrasonic sound is very narrow, the echoes from the posts at each side of the door mask the lack of an echo between them. A closed door, it would seem, could not be found at all. Conditions that

are hazardous are sometimes difficult to find by echo-ranging, since not all hazards are caused by the presence of obstacles. An open man-hole, a sudden step-down or a curb are as dangerous as solid obstacles,

yet it is difficult to identify either the hole or the step-down by echo-ranging. From the point of view of acoustic field theory, there is always a scattered wave whenever there is a discontinuity of any kind

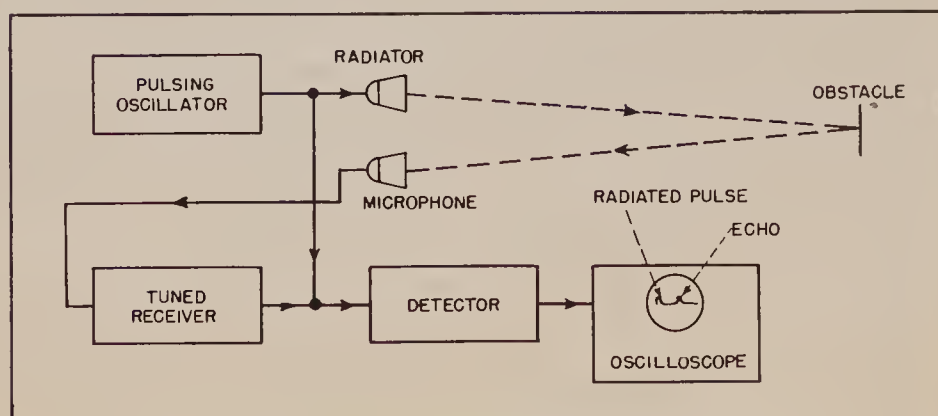
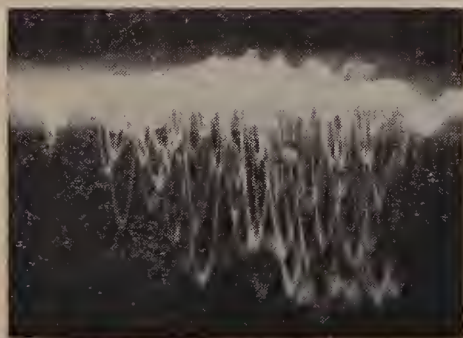


FIG. 2—Block diagram of a simple pulsed blind guidance system

FIG. 3—Oscillogram showing echo fluctuations as a person approaches



the return of its echo. For studying the properties of ultrasonic sound fields it is convenient to use an oscillographic presentation similar to the A-scan of radar. Such a presentation is, of course, useless to a blind man, but the information obtained from the simple pulse system has been invaluable in the laboratory. By means of such systems it has been possible to measure the magnitude of the scattered wave from a sharp step-down. It was also apparent, after working with the pulse system for a while, that the echo from an object as small as a fine thread might, under certain circumstances, be greater than the echo from a large, flat wall. At 65 kilocycles, an ordinary sewing thread at a distance of a foot or two and held normal to the beam, produces an easily detectable echo, while a very smooth wall at an angle to the beam may give no detectable echo at all. Inhomogeneities in the air cause the echoes from the objects ten or twenty feet away to fade and flicker, and at 30 kilocycles the echo from a wall about thirty feet distant may vary from zero to a strong echo that fills the whole oscilloscope screen. Echoes from objects having a complex shape are even more susceptible to flickering than the echoes from a simple object such as the flat wall. Sound reflected from various portions of the complex object may reinforce or cancel as the atmospheric conditions vary, and in such an instance it takes a very small change in the properties of the acoustic path to cause violent fluctuations of the echo. Most unstable of all is the echo from a complex moving object. Figure 3 shows the fluctuations that occur as a person walks toward the transducers. The frequency is 32

ample, the jingling of keys, if the or the blast of air from an air hose can cause trouble. The complete evaluation of any blind guidance device is in itself a major psychological problem. Since this phase of the work is carried on by the Haskins Laboratories, it will be reported elsewhere.

Transducers

While the requirements of effi-

ciency, bandwidth, transient response, small size and light weight are stringent, magnetostriiction transducers have been developed that have given satisfactory performance. The magnetostriiction transducers for use at 32 kilocycles have been described elsewhere; these transducers were satisfactory for experimental use but would be too large for a practical device. Magnetostriiction transducers for use at 65 kilocycles have also been developed. These are similar to the 32-kilocycle transducers but are correspondingly smaller so that their directional characteristics are approximately the same.

Separate but identical transducers are used for radiator and microphone. The transient response of the units does not permit use of a single unit for both functions. Figure 1 is a photograph of the double transducer units for 32 kilocycles and for 65 kilocycles. The beam width of a single transducer is about 6.5 degrees at the half-power point. The on-the-axis sensitivity as a microphone is 60 to 70 decibels below one volt per dyne per square centimeter. The bandwidth of a single unit is 300 to 500 cycles. In a pulse ranging system, this bandwidth is sufficient to resolve two objects spaced from 1½ feet to one foot apart.

Simple Pulse System

The simplest type of pulse echo-ranging system is shown in Fig. 2. A pulsing oscillator generates short pulses of ultrasonic frequency separated by a constant interval of time. The distance from the transducers to an object which reflects the ultrasonic pulses is determined by measuring the elapsed time between the radiation of a pulse and

in the path of the sound wave. The wave scattered back from a step-down, however, is so small that it might easily be mistaken for the wave scattered from a crack in the sidewalk.

Signal Presentation

Even if the desired information can be obtained by echo-ranging, there is still the problem of the presentation of this information to the blind subject. With the sense of sight no longer available, the information must be presented to one or more of the remaining senses. The most obvious method of presenting direction is to allow the transducer unit to be held in the hand so that the subject can scan his environment with the projected ultrasonic beam. When an obstacle is detected, its direction is thus the direction in which the transducer unit is pointed. This method is used in all systems described here.

Perhaps the most obvious method of distance presentation is aural. However, other types of presentation are possible and in some circumstances may be more desirable. Ultrasonic systems have been built that present the range information either aurally or tactually. Some of these systems have been modified so that the information is presented by direct electrical stimulation; for example, a controlled shock. Of the three methods, the most information can be presented aurally. However, blind subjects prefer not to use earphones since they interfere with normal hearing cues. While the use of a bone conduction receiver may be the most satisfactory compromise, the decision between types of presentation can only be made after tests with blind subjects.

A number of difficulties exist in ultrasonic systems, the main one being specular reflection of sound from large, smooth surfaces. Such a surface, unless it contains irregularities that scatter the sound, can be detected only when it is oriented normal to the beam. Fortunately, most flat surfaces encountered can be detected by the scattered sound. Ambient noise in the ultrasonic range can, occasionally, interfere with the desired signal. For ex-

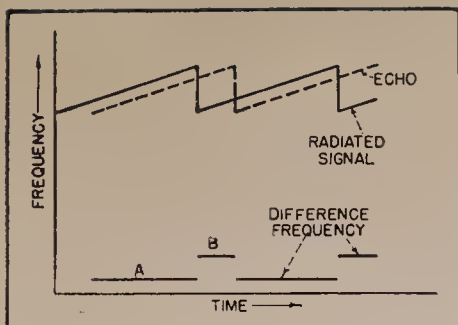


FIG. 4—Graphical representation of the sawtooth frequency modulation system

kilocycles and the total length of the sweep is equivalent to 18 feet. To obtain this photograph, the camera shutter was left open for the entire time it took the subject to walk up to the transducers.

First-Echo Pulse System

One type of pulse system often proposed for blind guidance causes the outgoing pulse to be initiated or triggered off by the echo. In such a system the repetition rate gives an indication of the distance, a fast repetition rate indicating a nearby object and a slow repetition rate indicating a distant object. This type of system should operate satisfactorily if only one echo is received for each radiated pulse. However, it often happens that echoes from more than one object are received in a single period. For example, if three echoes return after the first pulse, each of these three echoes will trigger off a pulse, and for each of these pulses there will be three more returning echoes. It is apparent that there results a continual multiplication of the number of pulses sent out so that the system quickly saturates and no useful information is obtained.

A system has been developed to avoid this difficulty by responding to the first echo only. It has a repetition rate that is a function of distance. This short-range obstacle-location system meets the following specifications: (1) the device responds to the first echo only; (2) the presentation is tactile; (3) the range is limited; (4) there is no detectable signal when no echo is received; (5) the frequency of the tactile presentation decreases with distance.

The range indication as given by the repetition rate varied in the

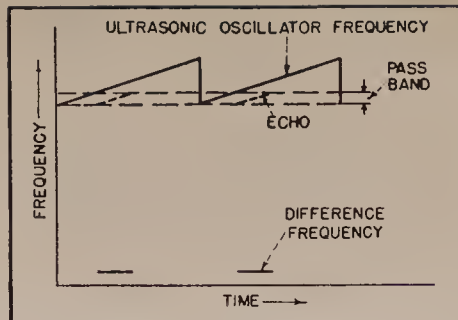


FIG. 5—Pulsed frequency modulation system employing ultrasonic oscillator

first-echo pulse system developed from about 30 pulses per second for nearby objects to about five per second for distant objects. The maximum range could be limited to any value between six and 20 feet. This system, however, had two important fundamental limitations.

First, the frequency range of the distance indication was insufficient for tactile presentation. The maximum repetition rate could not be increased since the period must be sufficiently long for all echoes to return in the same period in which the corresponding pulse was radiated. Reports from the testing psychologists indicate that a frequency range of 20 to 200 cycles per second should be provided for tactile presentation.

The second limitation was the effect of fluctuation of the echoes mentioned earlier. These fluctuations produced an instability in the signal which made it difficult to interpret. As the echo flickered, there was an occasional period in which the significant echo did not appear. In such event, the radiation of the next ultrasonic pulse did not take place until the normal idling period had passed. The pulses were thus unevenly spaced, making it

difficult to recognize any definite repetition rate.

To be sure that the range indication will be independent of the way in which the echoes might flicker, the indication of the distance to the reflecting obstacle should be definitely established by one sequence of events consisting of the radiation of the ultrasonic signal and the return of the echo. It should not be necessary for subsequent cycles of events to repeat consistently. In an oscilloscopic presentation, the position of the echo on the horizontal axis is fixed by the time that elapses between the radiation of the pulse and the return of the echo. No matter how violently the amplitude of the returning echo may fluctuate, the position of the echo on the oscilloscope remains substantially unchanged.

F-M Systems

A similar independence of range indication and echo amplitude can be attained with a frequency modulation ranging system. In such a frequency modulation system, the frequency of the ultrasonic signal is varied cyclically as a function of time. Since the echo is delayed by the time required for the signal to travel to the reflecting object and back to the transducers, there is a difference between the echo frequency and the frequency of the ultrasonic oscillator at the time the echo returns. This difference in frequency is also a function of the distance to the reflecting object. If the rate of change of frequency is chosen properly, the difference frequency can be made audible by mixing the oscillator signal and the echo in a nonlinear circuit. To de-

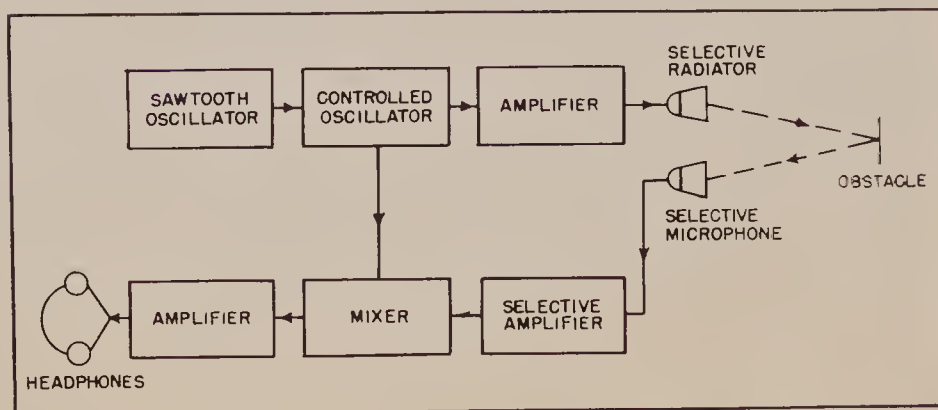


FIG. 6—Block diagram of the pulsed frequency modulation system

weight of the complete system, including transducers, headphones and batteries, is 5½ pounds. This particular system was designed to operate near 30 kilocycles. The maximum range depends upon the size and nature of the obstacle. A person in an open area can be detected at distances up to about 30 feet. In the judgment of blind subjects it was the most useful of the systems tested for actual outdoor situations.⁷

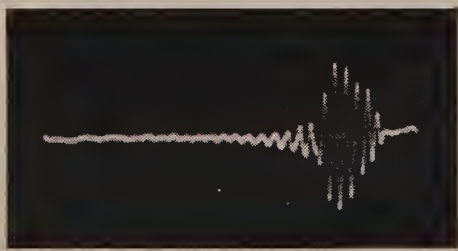
The two most obvious disadvantages of this model of the pfm system were the size of the transducers and the use of headphones. These disadvantages have, to a large extent, been overcome in a more recent model that operates at 65 kc and uses the smaller transducers shown in Fig. 1. A bone-conduction receiver is used instead of headphones. Although this model has not been completely tested by Haskins Laboratories, its performance appears to be at least equivalent to that of the 32-kilocycle model.

Although these units are larger than hearing aids and their power requirements are greater, neither their size nor their power requirements are unreasonable, especially at 65 kc. The information provided by such an echo-ranging system is different from that provided by a Seeing-Eye dog or a cane. Consequently the usefulness of such a system must be evaluated both by psychological tests and extensive use of the system by blind subjects. It is entirely possible that the information provided by any echo-ranging system may not be sufficiently valuable to a blind person to outweigh its inconvenience.

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FIG. 7—Oscillogram of audible signal from pfm guidance system



The frequency band of the sound actually radiated and received is limited by the pass band of the ultrasonic transducers. The received echo, then, is a pulse of ultrasonic energy of changing frequency that lasts about 50 milliseconds. A block diagram of the pfm system is shown in Fig. 6. The echo and the original oscillator frequency are combined in a mixer stage and the audible beat note is fed into a headset. The beat note appears as a series of pulses, as illustrated in the oscillogram in Fig. 7.

In the pfm system there is a single audio frequency corresponding to any given distance, and as long as the repetition rate is sufficiently slow that even the most distant echoes return before the new repetition period starts, there is no contradictory information supplied. Even when echoes from different distances arrive during the same period, the subject can learn to identify the different distances by listening for the various individual frequency components in the audio output. It is much the same sort of situation as learning to identify the notes of a musical chord, with the exception that in the output of the pfm system the low frequencies that correspond to nearby objects are heard first, and the higher frequencies that correspond to the more distant objects are heard slightly later.

The photograph shows an experimental version of the pfm system. The case houses a four-tube receiver, a six-tube transmitter, and batteries. Subminiature tubes are used in all positions except the ultrasonic output stage which employs a 3Q4. Filament drain is 370 milliamperes at 1.5 volts; plate drain is approximately 5 milliamperes at 45 volts. Total power demand is about 0.75 watt. The

ing obstacle, the only requirement is that the duration of the audible signal within one repetition period be great enough to permit recognition of the pitch. The duration of the signal can thus be as short as 40 milliseconds for the recognition of the pitch of signals above 100 cycles per second. It will not matter if, in the next repetition period, the echo fades out completely, for the accurate interpretation of the range signal does not depend upon the consistent repetition of the signal in every period. The most common types of modulation used in f-m ranging systems are sinusoidal and sawtooth modulation. Sinusoidal modulation results in an unnecessarily complex signal, and consequently will not be considered here. Sawtooth frequency modulation is illustrated in Fig. 4.

The radiated signal is represented by the heavy line that varies up and down in frequency as a function of time. The echo, shown by the dotted line, is delayed by the length of time required for the radiated signal to reach the reflecting obstacle and return. The difference in frequency between the radiated signal and the echo is shown as the solid lines A and B. It is seen that there are present in the beat note two frequencies. Frequency A rises as the distance between the radiator and the obstacle increases while frequency B becomes less. If we call the repetition period T and the delay time Δt , the beat note corresponding to an echo which is delayed by a length of time Δt will be indistinguishable from the echo which is delayed by an interval equal to $(T - \Delta t)$. The problem of finding one's way about with any ranging device is difficult enough without forcing the user to interpret contradictory signals.

PFM System

A system known as the pulsed-frequency modulation system or pfm has been developed to eliminate the confusing characteristics of the f-m systems described above. Figure 5 shows the way in which the pfm system functions. The ultrasonic oscillator varies in frequency following the sawtooth

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